PRODUCTION OF MAGNESIUM FROM THE GREAT SALT LAKE

by

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ABSTRACT

The relatively high concentration of magnesium chloride in the Great Salt Lake provides for commercial extraction of magnesium metal. Using natural geographical features and drawing on previous industrial experience, a consortium of commercial and manufacturing entities put together a system to extract and purify the magnesium minerals from the lake and generate magnesium metal. The process for producing metal is described. Products, commercial by-products of the process, and their uses are briefly described.

INTRODUCTION AND HISTORY

Through historical time, the Great Salt Lake has been recognized as a valuable source of minerals. In addition to the sodium chloride "salt" incorporated in its name, the lake's waters also serve as the raw material for the magnesium facility operated by Magnesium Corporation of America (MagCorp) at Rowley, Utah. That facility accounts for all of the United States' magnesium-metal production, and about 14 percent of the free world's magnesium-metal production.

Production of magnesium metal from Great Salt Lake has its roots from other places. During World War II, National Lead Industries began to develop technology for the production of magnesium by operating a government-owned magnesium plant at Lucky, Ohio, using the ferro-silicon process. The company gained additional expertise in the production of magnesium metal, in 1951, with the formation of a jointly owned company, Titanium Metals Corporation of America (TIMET), at Henderson, Nevada. Magnesium metal was used as the chemical-reducing agent in the production of titanium. After reduction, the magnesium forms magnesium chloride ($MgCl_2$), which is electrolyzed to recover both magnesium and chlorine.

In the early 1960s, National Lead began investigating the possibility of producing and selling commercial quantities of magnesium metal. In searching for sources of magnesium, National Lead Industries joined with Hogle-Kearns, a Utah investment firm, and Kerr McGee, a diversified chemical company, in a venture to assess the Great Salt Lake's potential for producing magnesium metal. The venture partners sought rights from the State of Utah to Stansbury Basin because they recognized its potential to be developed into an economical, natural solar pond system. The Stansbury basin is a shallow depression in the lake bed which is bounded on the east by Stansbury Island, on the west by the Lakeside Mountains, and on the south by the naturally increasing topography. To the northwest, the planned solar ponds would be bounded by a mud flat that is somewhat higher in elevation than the majority of the basin. To the northeast, the area between Badger Island and Stansbury Island consisted of relatively shallow water that could be diked, and still allow access to deep water for a constant supply of feed brine for solar evaporation.

During 1965 and 1966, National Lead Industries conducted pilot operations to select the best magnesium-producing process using Great Salt Lake brines. Scale-model solar ponds were constructed at Burmester, Utah, and a manufacturing pilot plant, designed for producing electrolytic-cell feed, was built near Lakepoint, Utah. Magnesium chloride product from this pilot plant was trucked 450 miles and fed into a prototype cell at TIMET in Henderson, Nevada. Based on the successes and data obtained from this early work, the decision was made in 1969 to build a magnesium plant at Rowley, Utah, utilizing brine from Great Salt Lake. By the time construction plans were finalized, National Lead had acquired sole ownership of the proposed magnesium operation.

Construction of the integrated facility began in 1970, with Ralph M. Parsons as the general contractor. The new magnesium manufacturing plant site was located ten miles north of Interstate 80 on the west side of the Stansbury basin. The exact location was fixed to straddle two power-district boundaries. This provided alternative sourcing of electrical power, a substantial component of the manufacturing cost. The "Rowley" plant site was named for Jeff Rowley, who was the CEO of National Lead during the period of construction. In addition to normal construction costs, it was necessary to construct 15 miles of paved highway, a railroad spur, a natural gas line, and a dedicated 138,000-volt power line to service the new plant.

Actual start up of the magnesium operations occurred in the summer of 1972. Initially, operations experienced substantial difficulties as viable operating systems were developed. It was necessary to completely shut down operations in 1975 to re-engineer some parts of the process. Norsk Hydro, a magnesium producer in Norway, was contracted to assist in this process, which included developing a system for the removal of boron. Boron, which occurs naturally in Great Salt Lake, had unexpected and adverse affects on the quality of the final magnesium product.

After the 1975 shut down, routine operations suffered economically from the higher than expected capitalization cost, and lower than expected plant productivity. In 1980, NL Industries (National Lead changed its name to NL Industries in the mid-70s) sold the magnesium operation to Amax Inc., a diversified mining and natural resource company.

Shortly after the transfer of ownership to Amax, a change in the weather pattern caused an unprecedented rise in the level of the Great Salt Lake. Amax spent millions of dollars to continue operation; much was spent to raise and fortify the dikes that separated the Stansbury basin ponds from Great Salt Lake. Expenditures were also required to expand the solar evaporation pond area to compensate for the mineral content dilution of the lake brine. Modifications were also made to the Rowley magnesium manufacturing process in an attempt to compensate for weaker than normal feed brines.

In spite of Amax's efforts to raise and fortify its dikes, a storm on June 7, 1986, coupled with record lake elevations, breached the main dike separating the solar ponds from the lake. Over the course of a week, the Stansbury basin ponds filled with 7 feet of lake water while the elevation of the main south arm of the lake dropped by an estimated 5.5 inches.

The extensive time and expense required to bring the flooded Stansbury basin ponds back into production, coupled with the uncertain future lake levels, caused Amax to examine alternative brine sources and solar-ponding sites. During the flooding, magnesium production continued at a reduced rate using concentrated magnesium chloride brines purchased and trucked in from Reilly Chemical near Wendover, Utah, and Leslie Salt located near San Francisco Bay, California.

After substantial analysis, it was determined, that an area near Knolls, Utah, comprised of mud flats interspersed with sand dunes, could be quickly converted into solar ponds at a reasonable cost. Brine from the New Foundland Bay part of the state's West Desert Pumping Project was available to fill the proposed ponds. The permits to use the Knolls site were obtained, and construction with an expedited completion schedule commenced in May of 1987. The engineering firm of Morrison-Knudsen acted as the general contractor. The construction included a six-mile feed canal, six pump stations, a maintenance shop and office facility, over 60 miles of containment dikes, and a 41-mile pipeline from the new ponds to the plant at Rowley. Sufficient construction was completed by December of 1987 to allow the Knolls Solar Evaporation Ponds to be filled.

The initial construction of the West Desert Pumping Project presumed that the high elevation of the lake would continue for an extended period. The project was somewhat abbreviated in order to conserve resources. Changes in the weather at the completion of construction caused the lake elevation to drop faster than was anticipated. With the lower lake level, the original pump station inlet canal would not supply a sufficient volume to the pumps to circulate lake water through the West Desert and fully utilize the newly constructed Knolls solar pond facility. In 1988, Amax assisted the State of Utah in extending the inlet canal to the Hogup Pump Station to provide suction-head protection and capacity to the West Desert Pumping Project. This was accomplished using a large cutter-suction dredge which was then

owned and operated by Amax.

The Knolls ponds were designed with the anticipation that the West Desert Pumping project would operate for only a limited period of time. As such, they were built to produce and store enough concentrated brine to supply feedstock to the Rowley plant for 10 to12 years after the State's pumping to the West Desert ceased.

The West Desert Pumping Project operated from April 1987 through June 1989, and then was shut down. Brine was generally accessible to Amax from the Newfoundland Bay until mid-1990 when the brine supply dried up. Since that time, brine has occasionally been available from the Newfoundland Bay during wet periods, or rain events, because of the re-dissolution of the salts left on the surface by the West Desert Pumping Project.

In 1989, Amax sold the magnesium facility to Renco Inc., a privately held company in New York. The magnesium operation was renamed Magnesium Corporation of America (MagCorp).

In the late 1980s and early 1990s, the level of the Great Salt Lake receded as quickly as it had risen in the early 1980s. By 1992, the lake level had retreated to a level that allowed MagCorp to begin the process of re-commissioning the ponds in the Stansbury basin. In 1995, the first brine harvest from the Stansbury basin ponds was brought into the plant.

ROWLEY MAGNESIUM PROCESS

Costs and reliability are both critical factors in any manufacturing process. The same is obviously true for magnesium operations at the Rowley plant. Operating decisions are made with the intent of reducing energy costs and maximizing equipment efficiency. The present Rowley process is described below.

Solar Evaporation

The raw material used in the manufacture of magnesium metal is a concentrated magnesium chloride brine. Magnesium, however, occurs naturally in the Great Salt Lake in very small quantities. The natural concentration of magnesium in the south arm of the lake ranged from a low 0.18 percent in 1986, when the lake level was at its zenith, to approximately one percent at the lake's historic low level in 1963. The nominal concentration of magnesium is about 0.4 percent by weight. To be an economically acceptable feed to the Rowley magnesium manufacturing process, a concentrated feed brine of greater than 8.0 percent (by weight) magnesium is required. To achieve this substantial increase in concentration from 0.4 percent to 8.0 percent magnesium, MagCorp employs the world's most extensive industrial use of solar energy in its Stansbury basin evaporation ponds. The ponds, constructed on lands leased from the State, occupy approximately 65,000 acres, with the actual area covered by water amounting to about 48,000 acres. Between 20- and 35-billion gallons of lake water are annually brought into the Stansbury basin ponds, depending on evaporative performance, and brine requirements. The basin is divided into smaller individual ponds, where efficient operation and maximum recovery are achieved by operating the ponds in a con-

tinuous or sequential mode, rather than letting individual ponds evaporate to the desired concentration. When operated this way, the brine advances through the ponds like a slow moving river that becomes shallower as concentration increases. The progressive concentration of magnesium is illustrated in table 1, which starts with the relative ion concentrations of Great Salt Lake brine, and then shows the effluent from three of the sequential ponds. The magnitude of this evaporation step is illustrated by the fact that less than one percent of the original volume of Great Salt Lake brine finally reaches the plant to be used in the manufacture of magnesium metal. During the concentration of the brine, about 5 million tons of mixed salts are deposited in the ponds each year.

Table 1. Percent of each ionic constituent in GSL brine and pond effluents (weight percent of ion in brine).

Ion	Great Salt Lake Brine	Effluent Pond No. 1S	Effluent Pond Pond No. 2WE	Effluent Pond No. 3C to Holding Pond
Mg	0.4	2.0	4.8	8.5
K	0.3	1.5	3.6	0.15
Na	4.0	7.0	2.6	0.2
Li	0.002	0.01	0.024	0.07
B	0.0018	0.009	0.021	0.06
Cl	7.0	14.0	16.0	22.6
SO$_4$	1.0	5.0	5.3	4.2

Because of Utah's seasonal variations in weather and temperature, and because the rate of evaporation is inversely related to the concentration of the brine, it is only possible to achieve the desired final brine concentration in the two or three hottest and driest months of the year, typically starting in the month of June. When the proper brine concentration is achieved, the brine is pumped to "deep-storage" holding ponds near the plant, that in aggregate can store up to three years supply of brine. Deep storage is required to avoid dilution by precipitation. In addition to the magnesium-rich brine product, which serves as the feed stock to the magnesium operation, sodium chloride, and potassium and magnesium salts are also recovered and sold, as will be described later.

Feed Preparation

The preparation of the concentrated magnesium chloride (MgCl$_2$) brine for use as feed to the electrolytic cells entails the removal of unwanted impurities, and further concentration. The process steps are outlined in figure 1.

The concentrated MgCl$_2$ brine is pumped from the deep-storage holding ponds into the production plant where it enters a series of reaction tanks where calcium chloride (CaCl$_2$) is added. Here, gypsum is precipitated and collected in a thickener. This reaction may be simplified as follows:

Equation 1. $MgSO_4 + CaCl_2 \longrightarrow CaSO_{4(ppt)} + MgCl_2$
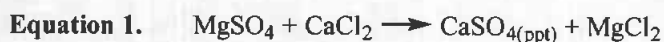
This step removes most of the sulfate, which may be unstable in molten systems.

Next, the brine next passes through a solvent extraction (liquid-liquid) step where a long-chain alcohol in a kerosene carrier is used to remove the naturally occurring boron from the solution. Boron is removed because it adversely affects the purity of the final product.

In a third step, the brine passes through a pre-heater vessel which utilizes waste process-heat to further concentrate the brine prior to its being fed into large spray dryers. The spray dryers convert the concentrated brine to a dry, gray MgCl$_2$ powder. The intent of this step is to remove all of the water, but some residual amount remains. During the drying process, some of the MgCl$_2$ is oxidized to magnesium oxide (MgO) through the hydrolysis of magnesium chloride, as shown in a simplified way as:

Equation 2. $MgCl_2 + H_2O \longrightarrow MgO + 2HCl$
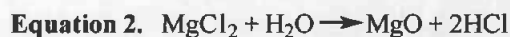
The spray-drying process is energized by the exhaust gases from natural-gas fired turbine/generators in a true utilization of co-generation technology. The electricity produced by the generators is used in the electrolysis of MgCl$_2$ described later. Gas burners are available to operate the spray dryer when the turbines are not available for use.

In the cell-feed preparation step, the spray-dried MgCl$_2$ powder is pneumatically conveyed to, and stored in, large bins until it is fed to the reactor, which is locally referred to as the "reactor" process. In the reactor, the MgCl$_2$ powder from the spray dryers is melted and further purified by introducing chlorine and carbon to remove MgO, and any remaining water. This is a continuous process where the spray-dried MgCl$_2$ powder is first fed into a brick-lined furnace known as a "melt cell" where it is melted by electrical-resistance heating. Then the molten salt overflows the melt cell, moves through a launder, and into a "reactor cell" where additional retention time brings the intended chemical reactions to completion. The melt temperature in the reactor cell is kept at 1,500°F by providing sufficient alternating current.

Removal of impurities is complex, but can be summarized by the following simplified chemical equations:

Equation 3. $2MgO + C + 2Cl_2 \longrightarrow 2MgCl_2 + CO_2$

Equation 4. $2H_2O + C + 2Cl_2 \longrightarrow 4HCl\uparrow + CO_2$
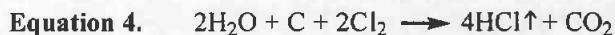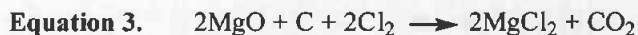
The finished, molten MgCl$_2$ product continuously overflows from the reactor cells and is transported to the electrolytic cells.

Hydrogen chloride (HCl), produced from the chlorination of water (H$_2$O) as shown in equation 4, is recovered as concentrated hydrochloric acid. This acid is subsequently reacted with limestone (CaCO$_3$) to produce the CaCl$_2$ (see equation 5) that is needed for desulfation process, and in the production of ferrous and ferric chlorides, which are sold as by-products.
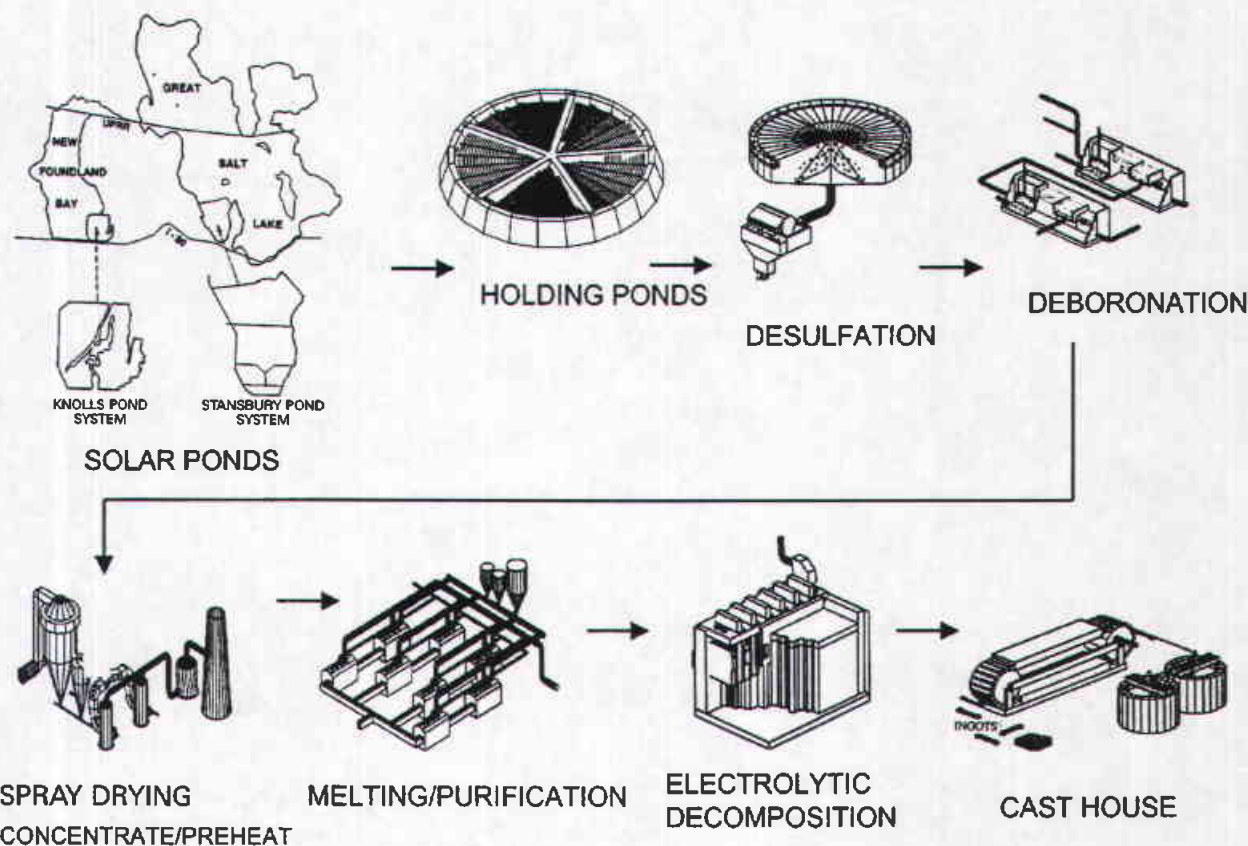
Equation 5. $2HCl + CaCO_3 \longrightarrow CaCl_2 + CO_2 + H_2O$

Figure 1. *Magnesium process flow diagram.*

Production and Handling of Magnesium Metal

Molten salt containing about 94 percent $MgCl_2$ is transferred to the electrolytic cells on a rigid schedule. In the electrolytic cells the molten magnesium chloride is electrochemically decomposed to molten magnesium and gaseous chlorine. The electrolytic cells are constructed as brick-lined steel furnaces equipped with negatively charged steel electrodes (cathodes), and postively charged graphite electrodes (anodes). Magnesium forms on the cathode and migrates to the top of the molten salt due to buoyancy. Chlorine gas forms on the anodes and is removed from the electrolytic cells by induced draft. The chlorine is then drawn to the chlorine recovery plant where it is cleaned, compressed and liquified. The magnesium metal is removed from the cells and it sent to the foundry. The design of electrolytic cells separates the molten magnesium metal from the gaseous chlorine to prevent chemical recombination. The majority of the electrolytic cells at Rowley (2002) are a modern design that was developed at Rowley over a period of years, and are commonly referred to as M Cells. The electrolytic cells are dependent on careful construction and electrode alignment for efficient operation, magnesium and chlorine recovery, and extended operation. External cooling is provided for temperature control. In addition to the "M Cells," Magcorp also utilizes the "Amax Sealed Cell" design which was developed under Amax's term of ownership in the 1980s.

The molten metal is transferred from the electrolytic cells to the foundry via mobile transports referred to as vac-uum wagons. These wagons utilize a stationary vacuum system to draw molten metal from the cell's molten-salt surfaces into a steel vessel. Air pressure is subsequently applied to force the molten magnesium from the steel vessel and transfer it to holding/refining furnaces. Here, the magnesium is refined and/or alloyed as required. The magnesium is then cast into ingots of varying shapes appropriate for the customer's needs. Ingots may vary in weight from 15 to 1000 pounds. Most magnesium shipments to MagCorp's customers are done by truck, with a lesser portion being shipped by rail.

USES OF MAGNESIUM

In 1997, the total world consumption of magnesium was estimated at 368,170 short tons. The plant at Rowley is among the largest in the free world. Its output represents about 14 percent of the world production, and over 50 percent of the domestic production.

The largest single use of magnesium is for alloying with aluminum to provide strength, malleability, and corrosion resistance. The aluminum beverage can is the largest single user, but significant quantities of magnesium are present in almost every structural use of aluminum ranging from window frames to aircraft components.

The second most important market for magnesium is in structural applications via die casting. The largest, and ever-increasing, volume of magnesium die castings is used in the

automotive industry, where magnesium's strength and light weight are being used to improve fuel economy. Magnesium die castings are also used in housings for many computers, cell phones, and other electronic components because of its electrical dampening properties. Other important uses of magnesium die-cast parts are in the manufacture of manual and power hand tools, where magnesium's light weight improves safety and operator performance.

Magnesium's electro-chemical potential is ideal for use in corrosion protection applications. A substantial amount of magnesium is consumed each year as high, electrical-potential sacrificial anodes which are installed for corrosion protection on oil, gas, and other pipelines, hot water heaters, and in other applications where cathodic protection is required.

When magnesium is added to iron, it causes brittle gray iron to be transformed into higher strength-ductile iron. Automotive crankcases, which used to be forgings, are now manufactured with ductile iron. The steel industry's preferred method of removing embrittling sulfhur compounds involves injecting powdered magnesium into the molten steel, after which the sulfur can be removed as a slag.

Magnesium is also used as a reducing agent in the production of titanium, zirconium, hafnium, and beryllium. Other chemical uses of magnesium include production of grignard reagent catalysts, motor oil additives, pyrotechnic materials, and as a pharmaceutical material.

CO-PRODUCTS AND BY-PRODUCTS

Chlorine

In addition to magnesium metal, MagCorp also produces and sells a number of co-products and by-products. Chlorine is a co-product of electrolytic magnesium production. For each pound of magnesium produced, approximately three pounds of chlorine are also produced. Much of the chlorine produced at MagCorp's Rowley operation is recycled in the process (see equations 3 and 4). Excess chlorine is transported by rail and sold in the Salt Lake area and throughout the Western United States. MagCorp accounts for about 0.3 percent of the United States' chlorine production.

The chlorine produced at Rowley has been used in the production of ferric chloride, plastics, leaching of gold-bearing minerals, and other general commercial uses. Other uses include water purification, medicines, and many chemicals, just to name a few.

Calcium Chloride

MagCorp produces calcium chloride by reacting limestone (previously oolitic sand was used) with hydrochloric acid in environmentally controlled equipment (see equation 5). One-third of the calcium chloride produced is used in MagCorp's brine-conditioning process for the removal of sulphate (see equation 1). The balance is available for outside sales. Elsewhere, calcium chloride is used as an additive to specialized concrete, as a dust suppressant, ice melting, in chemical manufacturing, in the paper industry, and for heavy-media purposes in oil field service.

Ferrous and Ferric Chloride

Iron chlorides (ferrous and ferric) are also produced at MagCorp's Rowley facility for outside sales. The by-product hydrochloric acid is reacted with a variety of economially acceptable metallic iron sources to produce ferrous chloride. Ferrous chloride can then be treated with chlorine to convert it to ferric chloride. Iron chlorides are sold mainly for sewage treatment. Other uses include metal treatment, producing iron-based chemicals, and as a chlorinating and oxidizing agents.

Brines and Sodium Chloride

By contractual arrangement, about 25 percent of MagCorp's total brine volume in its solar pond system is diverted to an adjacent sodium chloride operation where high-quality, commercial grades of salt (NaCl) are deposited. The bitterns (concentrated brines exiting the sodium chloride operation) are then returned to MagCorp's ponds for inclusion with the brine being concentrated for use in the production of magnesium metal. In MagCorp's solar ponding operation, a significant amount of NaCl is precipitated. Much of this is not commercially useful, however, due to impurities and remoteness of location.

Potassium and Magnesium Salts

As the brine in MagCorp's solar-evaporation ponds approaches the final desired magnesium concentration, mixtures of potassium and magnesium salts such as kainite, schoenite, and carnallite are being precipitated. These salts, deposited in the final ponds, are acceptable as feed stock for the commercial production of sulfate-of-potash fertilizer, and are, on occasion, harvested and sold for that purpose.

Potential By-Products

Other by-products are being considered to accompany the production of magnesium at Rowley, Utah. These products include commercial grades of hydrochloric acid, lithium metal or lithium compounds, and bromine compounds.

CONCLUSIONS

Magnesium is a versatile metal for which demand has grown in recent years due to its properties of good strength and low density. The minerals in the Great Salt Lake serve as a source of raw material for one of the world's significant and successful magnesium producers. The unique nature of the Great Salt Lake provides substantial advantages to the recovery process as well as creating special challenges. The abundant volume of magnesium (even at dilute concentrations) in the Great Salt Lake, in combination with the use of solar energy, provides the basis for an attractive raw-material source. The chemistry of the lake, and the extraction process used, result in production of magnesium metal with few impurities. The challenge of developing a commercially viable extraction process has taken years to refine due to the unique and distinctive nature of the manufacturing process.

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by Dr. Robert Toomey

NL Industries

INTRODUCTION

In 1940, NL Industries began to develop its technology for the production of magnesium by operating a government magnesium plant using the ferro silicon process at Lucky, Ohio, during World War II. The company continued development of its expertise with the formation in 1951 of a jointly-owned company, the Titanium Metals Corporation of America at Henderson, Nevada. Magnesium metal is used in the reduction of titanium and the magnesium values are then recovered as $MgCl_2$, which is electrolyzed to recover both magnesium and chlorine. In the 1960's, NL Industries began an active investigation into the possibilities of producing and selling commercial quantities of magnesium metal. In searching for additional sources of magnesium, NL Industries became aware of the potential of the Great Salt Lake. A review of the various sources of magnesium led to the selection of the Great Salt Lake as the preferred place to locate a plant.

During 1965 and 1966, NL Industries conducted pilot operations to select the best process for use with Great Salt Lake brines. Solar ponds were constructed at Burmester, Utah, and a pilot plant for producing cell feed was built at Lakepoint, Utah. Product from this pilot plant fed a proto-type cell at TIMET in Henderson, Nevada. From this program a decision was made in 1969 to build a magnesium plant at Rowley, Utah, to utilize brine from the Great Salt Lake.

ROWLEY MAGNESIUM PROCESS

Costs and reliability were both critical factors in determining the process to be selected for the Rowley plant. Even at this early stage considerable effort was spent in reducing the energy consumption to as low a value as possible per pound of magnesium produced. From the early pilot plant work and through the initial plant operation, process steps were selected and modified in order to reach these objectives. The present Rowley process is described below.

Solar Evaporation

The first step in the process is the use of solar energy to perform the major part of the concentration of the magnesium values. A 25,000 acre pond system was built in the Stansbury Basin which is west of Stansbury Island and south of Badger Island. This basin is divided into three ponds where the desired brine concentration of 7.5% magnesium by weight is achieved. The progressive concentration of magnesium is illustrated in Table I, which shows the relative concentrations of the Great Salt Lake and the effluent from the three ponds in sequence. The magnitude of this evaporation step is illustrated by the fact that less than three percent of the volume of the original Great Salt Lake brine reaches the plant holding pond. In concentrating the brine over 3,000,000 tons of salts are deposited in the ponds each year.

Table I. Percent of each constituent.

	Great Salt Lake Brine	Effluent Pond No.1	Effluent Pond No.2	Effluent Pond No. 3 to Holding Pond
Mg	0.4	2.0	4.8	7.5
K	0.3	1.5	3.6	0.8
Na	4.0	7.0	2.6	0.5
Li	0.002	0.01	0.024	0.06
B	0.0018	0.009	0.021	0.054
Cl	7.0	14.0	16.0	20.3
SO4	1.0	5.0	5.3	4.4

Because of the seasonal variations in weather and temperature in Utah, evaporation of this quantity of brine must take place within the three or four hottest and driest months starting sometime in May. When the proper concentration is achieved, the concentrated brine is pumped to a holding pond, which can store up to two years' supply of brine. This storage is required to insure an adequate supply of brine during a year when the weather conditions would not permit adequate evaporation. Additional separation of solids and concentration is usually achieved in the holding ponds. Thus, the concentration of magnesium is usually brought to an excess of 7.5% Mg or 30% $MgCl_2$ with very little energy input besides solar evaporation.

Feed Preparation

The feed preparation for the electrolytic cells consists of further concentrating the brine, removing unwanted impurities, adjusting for the correct proportions of other salts with the $MgCl_2$, and the melting and final purification of the molten $MgCl_2$. The process steps are outlined in Figure 1. The brine is pumped in from the holding pond and is first heated and concen-
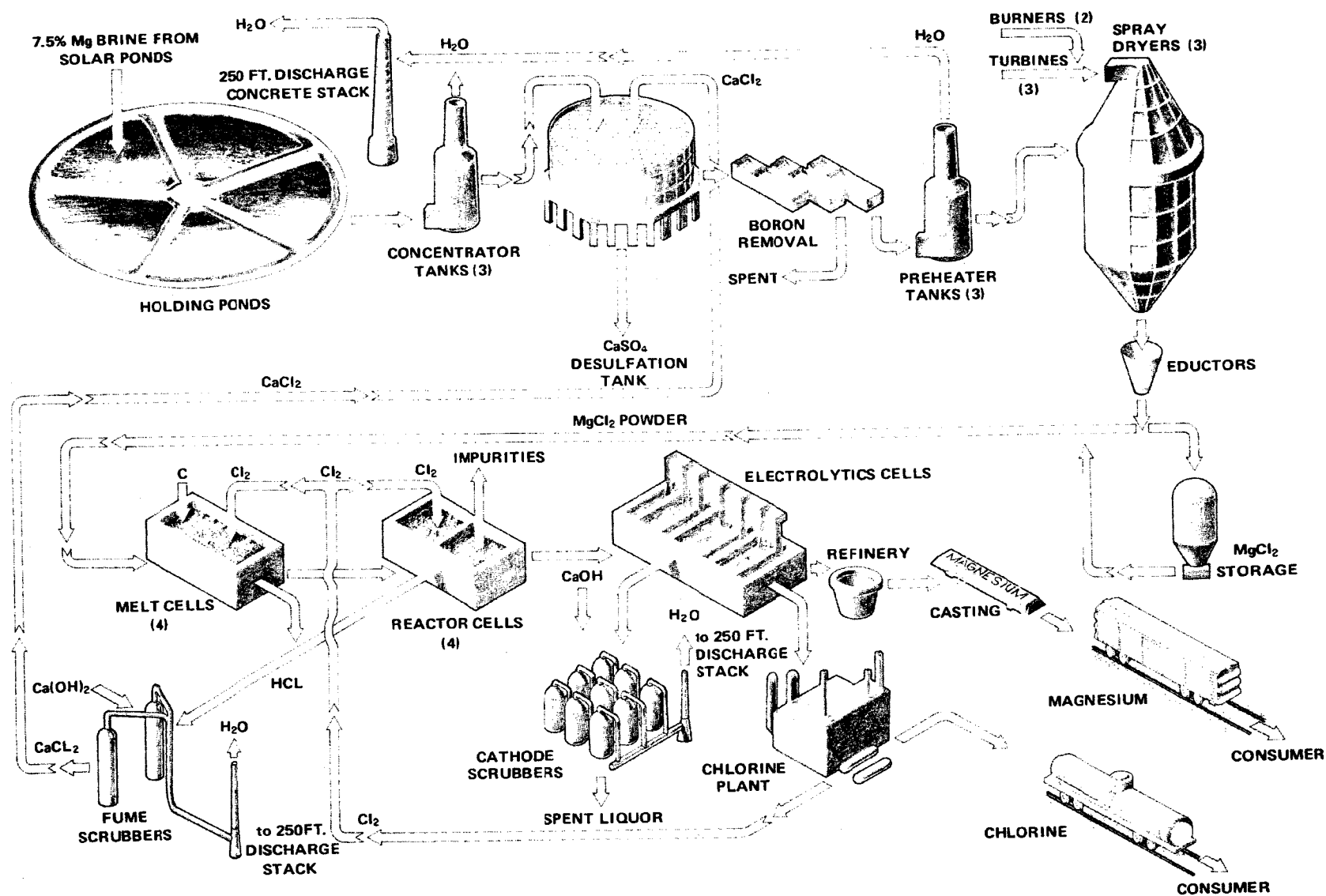
7.5% Mg BRINE FROM
SOLAR PONDS

H_2O

250 FT. DISCHARGE
CONCRETE STACK

H_2O

$CaCl_2$

H_2O

BURNERS (2)

SPRAY
DRYERS (3)

TURBINES
(3)

CONCENTRATOR
TANKS (3)

BORON
REMOVAL

SPENT

PREHEATER
TANKS (3)

HOLDING PONDS

$CaSO_4$
DESULFATION
TANK

EDUCTORS

$CaCl_2$

$MgCl_2$ POWDER

IMPURITIES

ELECTROLYTICS CELLS

$MgCl_2$
STORAGE

C

Cl_2

Cl_2

Cl_2

REFINERY

MELT CELLS
(4)

REACTOR CELLS
(4)

CaOH

H_2O

to 250 FT.
DISCHARGE
STACK

CASTING

MAGNESIUM

$Ca(OH)_2$

HCL

H_2O

CATHODE
SCRUBBERS

CHLORINE
PLANT

CONSUMER

$CaCL_2$

FUME
SCRUBBERS

to 250FT.
DISCHARGE
STACK

Cl_2

SPENT LIQUOR

CHLORINE

CONSUMER

Figure 1. Schematic diagram showing the production of magnesium metal and chlorine gas from the brines of the Great Salt Lake, Utah.
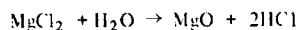
trated. After concentrating, it is reacted with $CaCl_2$ and the resulting gypsum is precipitated and collected in a thickener. This reaction is as follows:

Equation 1.

$$MgSO_4 + CaCl_2 + 2H_2O \rightarrow CaSO_4 \cdot 2H_2O + MgCl_2$$
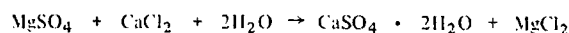
This step removes most of the sulfate, which is not acceptable in electrolytic cell feed. Due to the concentrating and subsequent cooling a majority of the remaining potassium and sodium values are also precipitated as solids in the thickener. The potassium is precipitated primarily as carnallite, $KCl \cdot MgCl_2 \cdot 6H_2O$, and the sodium as NaCl. The brine next passes through a liquid-liquid extraction step whereby the boron values are removed, as this impurity is also very detrimental to electrolytic cell operation. Next, the brine passes through a preheater in which it is heated and further concentrated prior to being fed to spray dryers. The spray dryers convert the concentrated brine to a dry $MgCl_2$ powder. This product contains about 4% MgO and 4% combined water. The MgO is formed by hydrolysis of $MgCl_2$ as shown:

Equation 2.

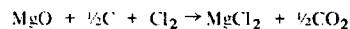$$MgCl_2 + H_2O \rightarrow MgO + 2HCl$$

Utilization of energy in the feed preparation step of the plant is extremely efficient. In order to ensure the availability of some on-site power, part of our power is generated in gas turbines. After producing power the exhaust gases pass from the generator to the spray dryer at approximately 930°F where the heat is used to form the magnesium chloride powder. These gases leave the spray dryer at about 550°F and are then used as the heat source in the concentrating and preheating of the brine prior to feeding it to the spray dryer. This gives an overall energy utilization of over 90%. Gas burners are available to operate the spray dryer when the turbines are not in use.
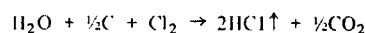
The spray-dried powder is stored until fed to a melt cell. In this vessel the powder is melted and further purified with chlorine and other reactants to remove MgO, water, bromine, and other impurities including most heavy metals. This is a continuous process and as powder is fed to the melt cell, molten salt overflows from the melt cell through a launder and into a reactor cell where the purification is completed. The reactor cell vessels are brick lined and approximately 13' × 17' × 8' deep. The melt temperature is kept at 1500°F by providing sufficient alternating current to maintain this temperature.

Removal of impurities is complex but can be summarized by the following simplified equations:
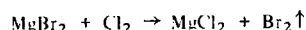
Equation 3.

$$MgO + \tfrac{1}{2}C + Cl_2 \rightarrow MgCl_2 + \tfrac{1}{2}CO_2$$

Equation 4.

$$H_2O + \tfrac{1}{2}C + Cl_2 \rightarrow 2HCl\uparrow + \tfrac{1}{2}CO_2$$

Equation 5

$$MgBr_2 + Cl_2 \rightarrow MgCl_2 + Br_2\uparrow$$

The product continuously overflows from the reactor cells and is fed directly to the electrolytic cells. The specifications for this material are as follows:

Bromine	Less than 0.01%
Boron	Less than 0.001%
Magnesium Oxide	Less than 0.2%
Water	Less than 0.2%
Sulfate	Less than 0.01%

HCl produced from the chlorination of water as shown in Equation 4 is recovered as concentrated hydrochloric acid which is subsequently reacted with lime to produce the $CaCl_2$ needed for desulfation:
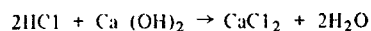
Equation 6.

$$2HCl + Ca(OH)_2 \rightarrow CaCl_2 + 2H_2O$$

Production and Handling of Magnesium Metal

Molten salt containing about 94% $MgCl_2$ is transferred to the electrolytic cells on a rigid schedule. The cells at Rowley are essentially a modification of the I.G. Farben cell developed in Germany in the 1930's. These are normally referred to as I.G. cells and figure 2 shows a sketch of a typical cell. This cell consists usually of three to five graphite anodes with steel cathodes on either side. Semiwalls extending from the top of the cell down into the bath isolates two gas compartments. The gas compartments around the anode collect the chlorine gas, which is generated on the anode surface. The chlorine is then pumped to the chlorine recovery plant. The cathode compartment collects the magnesium metal which floats on the salt. The magnesium metal is removed from the cells each day and sent to the foundry. (Sufficient air is passed over the cathode compartment to remove any fumes and then through a scrubber in order to keep the environment around the cells in satisfactory condition). The metal transferred to the foundry is conditioned, purified as needed, alloyed as required, and poured into molds for shipment. These

molds may vary from 16 pounds to 500 pounds or more and may be in the form of special shapes in order to serve specified end uses.

USE OF PRODUCTS

In 1977 the total free world consumption of magnesium approached 220,000 short tons of which about 120,000 tons were consumed in the United States. The plant at Rowley is the third largest in the free world and represents about 10% of the world production and 20% of the domestic production.

The largest single use of magnesium is for alloying aluminum to provide strength, malleability, and corrosion resistance. The aluminum beverage can is the largest single user, but significant quantities of aircraft and automotive sheet also require magnesium additions.

When magnesium is added to iron, brittle gray iron is transformed into higher strength ductile iron. Automotive crankcases, which used to be forgings, are now ductile iron. Recently, magnesium has been injected into steel to remove embrittling sulphur compounds.

Magnesium is used as a reducing agent in the production of titanium, zirconium, hafnium, and beryllium. Other chemical uses are as a grignard reagent, motor oil additive, pyrotechnic material, and as consumable anodes for cathodic protection.

As a structural material, magnesium is most viable as a die casting for chain saws, lawn mower housings, and the famous Volkswagen Beetle engine. Volkswagen is still the largest structural user of magnesium for engine and transmission components. NL supplies magnesium to Volkswagen's Brazilian plant for this purpose. Extrusions, tool plate, sheet, and plate also find a variety of uses.

While most of the magnesium produced is for domestic consumption, NL has shipped material overseas primarily to Europe, South America, and Japan.

A co-product to magnesium is chlorine, most of which is recycled in the process; however, excess chlorine (approximately 18,000 ton/year) is being sold in the Salt Lake area and the western United States. Chlorine has a variety of chemical uses and is also used in water purification. The plant at Rowley provides a Utah source of chlorine to replace that previously shipped in from the Pacific Northwest.

Other by-products presently being considered from the production of magnesium at Rowley, Utah are $CaCl_2$, HCl, lithium compounds, and bromine compounds. In addition, millions of tons of salt are being deposited in the ponds. These salts are largely sodium chloride and various sulfates. Sales of these salts, direct or after modification, will add potential income in the future.
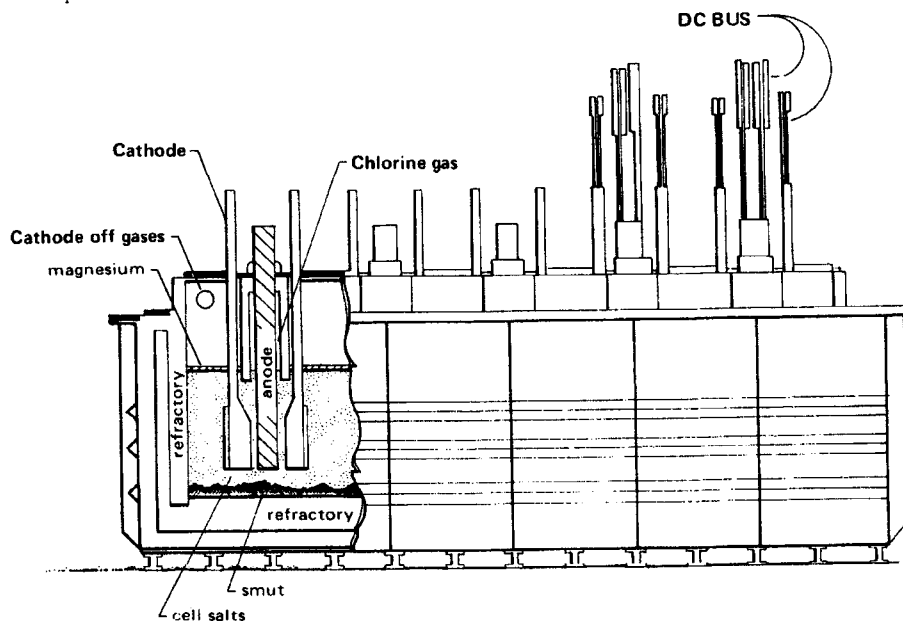

Figure 2. Typical I. G. electrolytic cell used for the production of magnesium metal and chlorine gas.

MAGNESIUM METAL FROM THE GREAT SALT LAKE

by

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NL Industries, Inc.
Magnesium Division
Salt Lake City, Utah 84116

MAGNESIUM METAL FROM THE GREAT SALT LAKE

INTRODUCTION

Ten years ago, NL Industries began an active investigation into the possibilities of producing commercial quantities of magnesium metal. NL Industries had been active in magnesium metal production in the past. We had operated a government magnesium plant using the ferro silicon process at Lucky, Ohio during World War II. Since early in the 1950's we have been involved in the production of magnesium metal at Henderson, Nevada as part of a titanium plant through our affiliate, TIMET.

A review of the various sources of magnesium led to the selection of the Great Salt Lake as the preferred place to locate a plant. Development work was done on utilizing this particular raw material, and a plant was designed and built to produce 45,000 tons of magnesium per year along with by-product chlorine. The plant is shown in an aerial photograph in Figure 1. Pilot work was done to seek a process for this location, to minimize raw material costs, and to lower power costs. Power costs are always a major factor in a process requiring electrolytic cells, and now under present day conditions minimizing the use of power is even more important in extending this country's overall power supply.

ROWLEY MAGNESIUM PROCESS

First, it is desirable to look at the basic process steps at Rowley. These are shown in Figure 2. Brine containing 7.5% Mg is pumped from our solar evaporation ponds to a holding pond which holds over a year's supply of feed for the plant. From this holding pond, the brine is first pumped

to a desulfation step where calcium chloride is added in order to reduce the sulfate value of the brine to an acceptable level for cell feed. The brine is then concentrated and passed through a crystallizer whereby carnallite, $MgCl_2 \cdot KCl \cdot 6H_2O$, is precipitated and removed from the brine. The brine is then preheated and pumped into one of three large spray dryers. The spray dryers produce a powder containing a minimum quantity of oxygen in the form of MgO and H_2O. Less than 5% of each component can consistently be produced.

The purpose of the steps up to this point is twofold. First, to produce a magnesium chloride solid which contains the desired amount of calcium, sodium and potassium chlorides which are required in the electrolytic cells to maintain the proper magnesium chloride content. Because the electrolytic cells must be operated at low $MgCl_2$ contents, some addition of these other salts is always required to maintain the proper composition as metal and sludge are removed from the electrolytic cells. The second purpose of these steps is to maintain the bulk of the $MgCl_2$ that is originally in the brine as $MgCl_2$ and minimize the conversion to MgO as the last water molecule of hydration is largely removed.

The spray dryer product is then melted, purified and sent to the electrolytic cells where magnesium and chlorine are produced. Our cells are a modification of the electrolytic cells developed by I.G. Farbin Industries of Germany in the Thirties, and are normally referred to as IG Cells. Figure 3 shows a sketch of a typical IG Cell. This cell consists usually of 3 to 5 graphite anodes with steel cathodes on each side. Semiwalls extending from the top into the bath isolate the two gas compartments. The gas compartment around the anode collects the chlorine gas for recovery,

while the cathode compartment collects the metal and allows for the passage of air over the compartment in order to cool the cell and carry fumes from this area to a scrubbing system.

The magnesium is removed from the cells, conditioned, alloyed as required, and poured into molds for shipment. Chlorine is cleaned, compressed and pumped to railway cars for shipment.

CONSIDERATION OF MAGNESIUM PROCESSES

This simplified process description as presented does not, of course, reflect some of the complexities which exist in this process. Some general comments on processes for producing magnesium metal are in order. One of the most difficult areas and one in which considerable work has been done throughout the world is in the separation of magnesium chloride from its chemically bound water. This separation is necessary to some extent in all the presently developed processes. Besides this major separation of water, there are many other impurities that will affect the operation of a cell. This becomes a very intriguing problem if one realizes that there is a very definite relationship between the effect of impurities which exist in the feed to the electrolytic cell and the almost infinite design parameters that can be built into a cell. It is an oversimplification to say that cells in general must contain less than certain impurity levels in order to get a specific result. This explains why there are many apparently conflicting statements to be found in the literature. In some cases, considerable variation in impurity levels can be tolerated by design considerations in the cell. This is amply demonstrated by the Dow process which uses a very impure feed so far as water is concerned, because the design of that cell

was made to accept that level of impurity and produce a product at a satisfactory cost. On the other hand, the IG Cell requires much higher removal of water and oxide in order to get any reasonable current efficiency. Concentrations on the order of 0.1% to 0.2% or less are required for optimum operation.

The effect of cell design and operation can also affect the allowable levels of other impurities. The literature has many examples of studies of impurities, and the levels that can be tolerated for specific performances. These impurities which are or can be found in undesirable quantities include magnesium oxide, water, hydroxyl group, bromine, boron, iron, carbon, sulfur and titanium.

Different sources of ores or brines will, of course, contain a wide variety in the level of the various impurities. For this reason, the steps in the purification of the magnesium values from these various sources will vary with the source and, in fact, this could dictate changes in cell design. In other words, both the preparation of cell feed and cell operation and design must be directly related to the source of raw material.

The key to success of any electrolytic magnesium process really lies in the effective operation of the electrolytic cells. This is where the metal is made, and this is where high power costs are involved. For optimum cell operation, in spite of the above comments on interaction between impurities and cell design, the best operation of any cell is going to occur in general with the highest purity feed. The problem then becomes one of taking a specific raw material source, reducing impurities as far as can be economically justified, and then feeding this material to an

electrolytic cell so designed to minimize the overall cost that will produce a satisfactory quality metal. An infinite number of variations are available for consideration and testing.

This problem is made even more challenging from an engineering viewpoint in the fact that relatively pure molten magnesium chloride is very difficult to handle. It is easy to underestimate the problems involved in handling, moving and purifying magnesium chloride.

ITEMS OF INTEREST IN THE ROWLEY PROCESS

1. Solar Evaporation. Solar evaporation was selected to perform the primary removal of the majority of water as well as other materials from the magnesium chloride, and this has proven to be a low cost method for reachin, a brine containing 30% contained magnesium chloride.

2. Impurities. After concentration, spray drying and purification, the magnesium chloride content will be in excess of 90% magnesium chloride. Most of the remaining material consists of calcium chloride, sodium chloride and potassium chloride which can be adjusted to some extent in the process to control the composition of the salt in the electrolytic cells. The salt in the electrolytic cell is maintained at a magnesium chloride content between 10 and 22% magnesium chloride. Reduction of MgO and H_2O has already been mentioned as an important factor. For those impurities in the Great Salt Lake, we are specifically interested in the overall process to hold the concentrations going to the electrolytic cells below the following figures:

	Percent in Cell Feed
Bromine	<0.01
Boron	<0.0020
Magnesium Oxide	<0.2
Water [incl. (OH)]	<0.2
Sulfate	<0.01

3. **Lithium.** One "impurity" in the Great Salt Lake actually contributes a distinct advantage to our process. The presence of lithium in the brine gives us the ability to control the lithium content of the salt in our electrolytic cells to the optimum level. Figure 4 is taken from a patent by F. E. Love[1] and shows that as one increases the lithium content the conductivity of the bath increases and therefore the voltage for a given throughput is appreciably decreased.

4. **Power Consumption--Feed Preparation.** There are various costs involved in the operation of the electrolytic cells, but the most important cost is the power cost. This is presently a factor not only in the actual cost, per se, but also in the need to minimize our consumption of power. The two principal uses of power are in the feed preparation and in the electrolytic cells. In order to insure the generation of some on-site power, we generate part of our own electrical power in turbines. Figure 5 shows the equipment through which the gases from the turbines pass to maximize heat recovery. The gases leaving these turbines are first the source of heat for vaporizing the final water in the spray dryers. After the spray dryers the gases are used both to provide the heat source for heating the brine and for evaporating water prior to the spray dryer.

5. **Power Cost--Electrolytic Cells.** The cost of power for the electrolytic cells is of prime concern on this process. Power costs can be looked at as a function of two items, the average voltage required across the cell and the magnesium current efficiency. This latter term is defined as the percentage of metal actually collected for a given amount of current passed

through, as compared to the theoretical metal possible to generate with that current. Table I shows the generalized relationship between the power consumption and the voltage and current efficiency. The decomposition voltage is 2.6, which is essential for the breakdown of the magnesium chloride. Commercial cells can be developed that would result in voltages from somewhat over the decomposition voltage to voltages of the order of 3 and 4 times the decomposition voltage. On examination of this table, it is obvious that the selection of the raw material, the purification of the feed, and the design of the cell must be directed toward minimizing cell voltage while holding the current efficiency at a reasonably high level. As noted above, one of the advantages of operating on the Great Salt Lake is the presence of lithium in the feed and the ability to control the lithium content at the optimum level. Thus, the Great Salt Lake gives us a decided advantage.

6. <u>Chlorine Production.</u> This process, as installed, produces both magnesium and chlorine. Part of that chlorine is reused in the process and the remainder is available for sale. One objective of the process as designed and installed was to keep the original magnesium chloride to the extent possible as magnesium chloride throughout the process so that the use of chlorine or HCl would not be required to convert the magnesium in some other form to magnesium chloride. Essentially all the magnesium values in the brine as either the chloride or the sulfate enter the spray dryer as the chloride except for the losses in the process principally as carnallite. Over 90% of the $MgCl_2$ going into the spray dryer leaves the spray dryer in the form of $MgCl_2$.

CONCLUSION

The value of the minerals in the Great Salt Lake has brought NL Industries to Utah and resulted in the design, construction and operation of a plant for the production of magnesium metal.

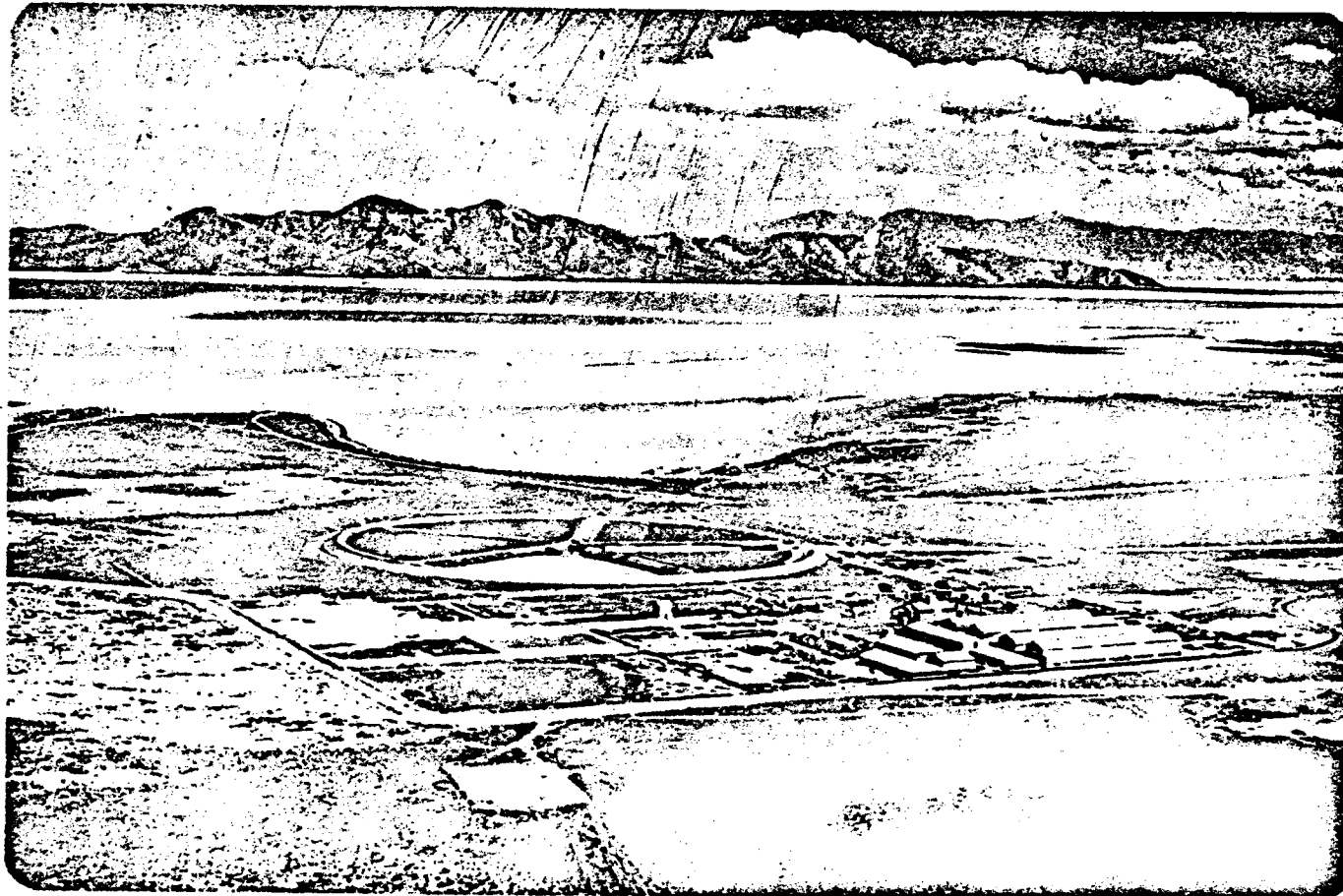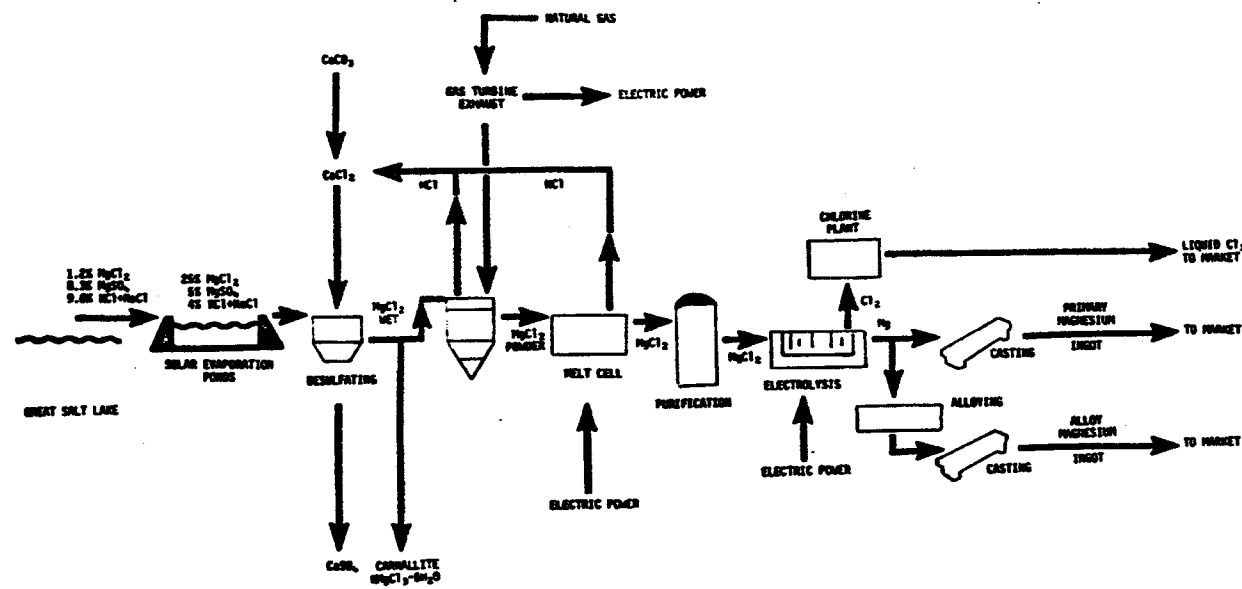## REFERENCES

[1] F. E. Love, U.S. Patent 3,389,062.

Figure 1.   Aerial View of Plant

N Mg
INDUSTRIES

MAGNESIUM DIVISION

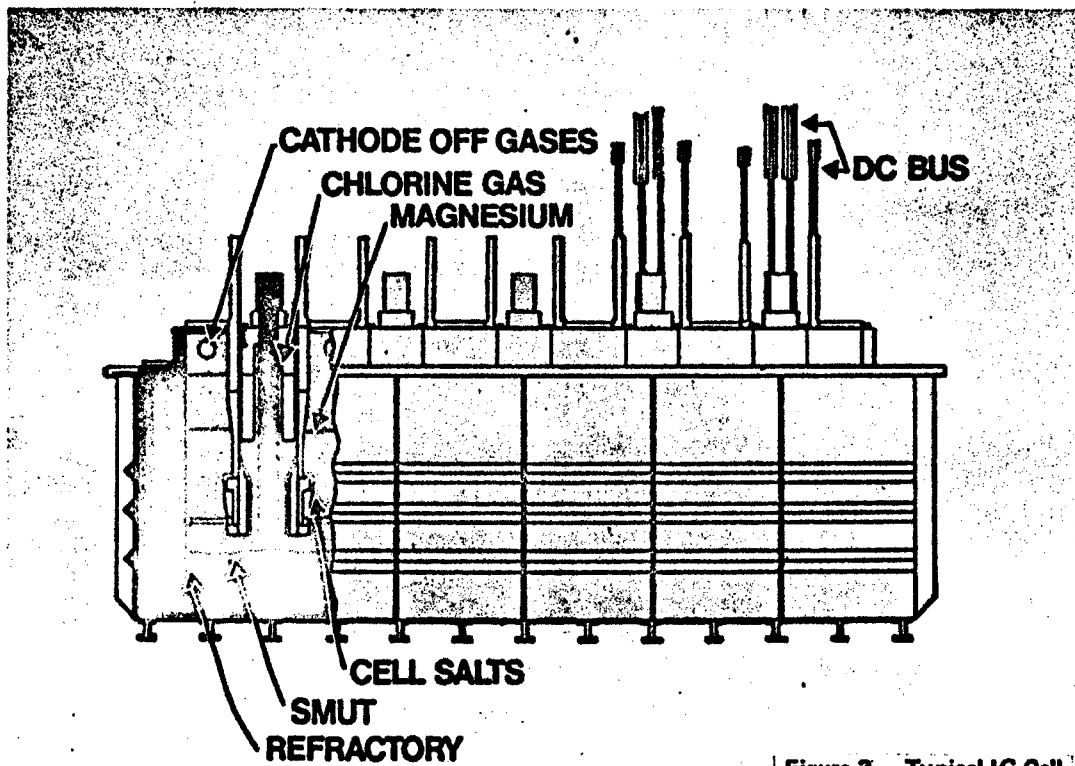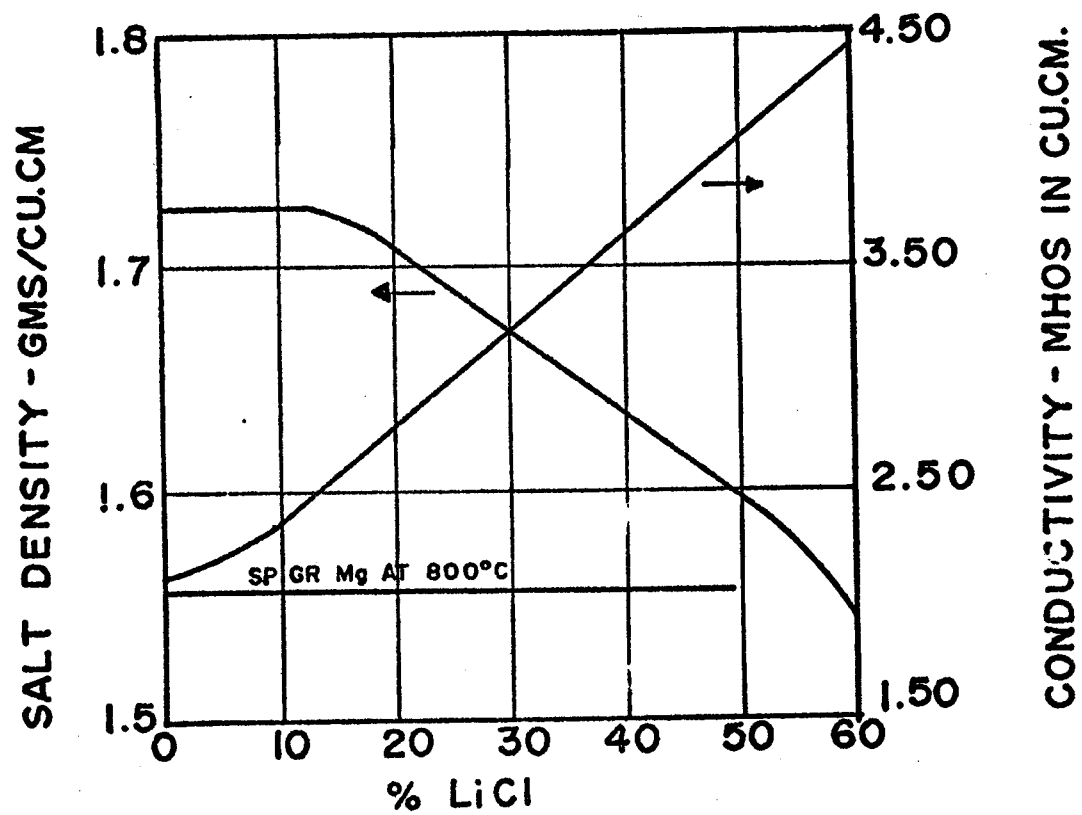CHEMICAL PRODUCTION OF MAGNESIUM AND CHLORINE

Figure 2.

CATHODE OFF GASES
CHLORINE GAS
MAGNESIUM
DC BUS
CELL SALTS
SMUT
REFRACTORY

Figure 3. Typical IG Cell

FIGURE 4

SPRAY DRYER TRAIN-GAS FLOW
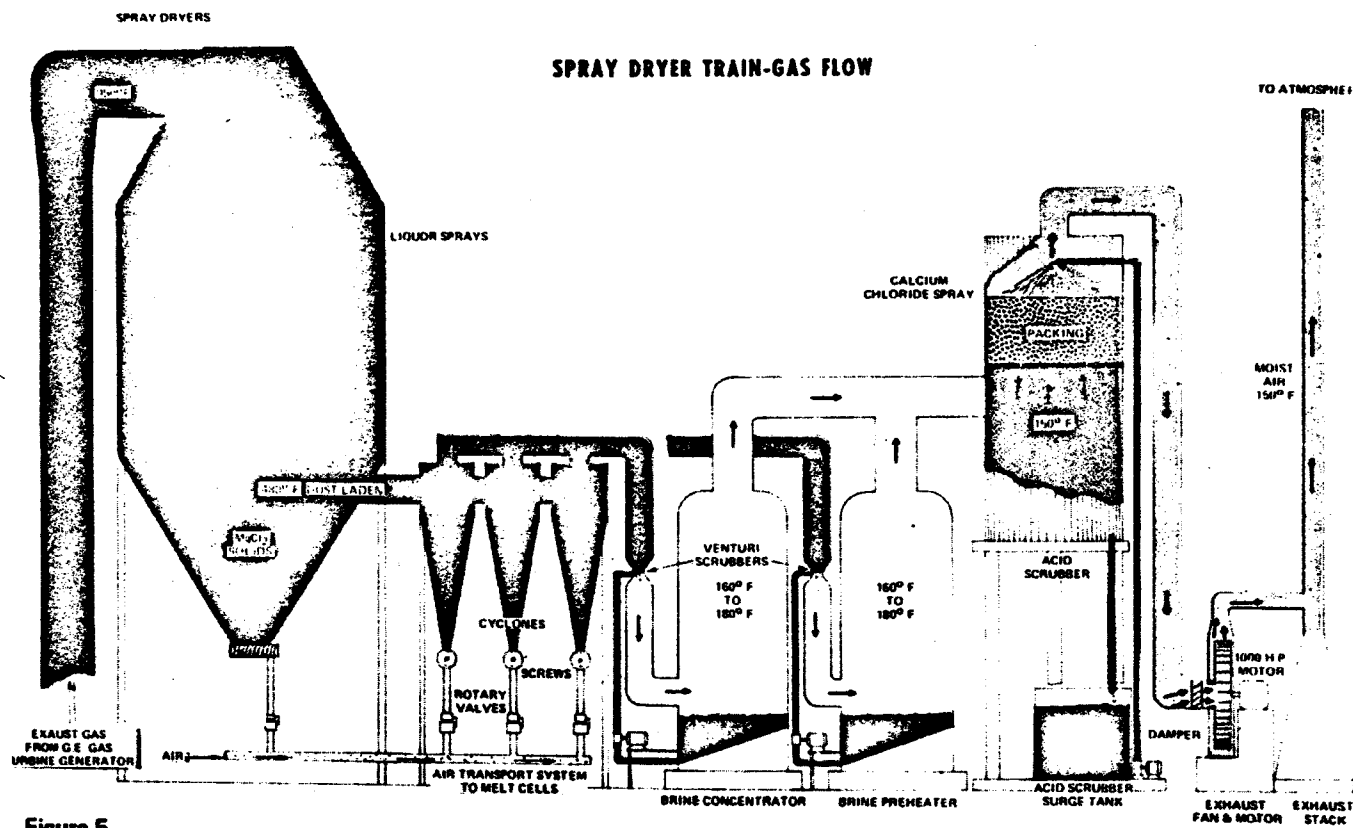
Figure 5.

TABLE I

KWH PER POUND OF MAGNESIUM

CURRENT EFFICIENCY	60%	70%	80%	90%	100%
CELL VOLTAGE					
5.5	9.17	7.86	6.88	6.11	5.50
6.0	10.00	8.57	7.50	6.66	6.00
6.5	10.83	9.29	8.13	7.22	6.50
7.0	11.67	10.00	8.75	7.78	7.00
7.5	12.50	10.71	9.38	8.33	7.50
8.0	13.33	11.42	10.00	8.89	8.00
8.5	14.17	12.13	10.62	9.44	8.50
9.0	15.00	12.85	11.25	10.00	9.00

PRODUCTION OF MAGNESIUM FROM THE GREAT SALT LAKE
by Dr. Robert Toomey Amended by Lee R. Brown 1991

Magnesium Corporation of America
(Magcorp)

INTRODUCTION

In 1940, NL Industries began to develop its technology for the production of magnesium by operating a government magnesium plant using the ferro silicon process at Lucky, Ohio, during World War II. The company continued development of its expertise with the formation in 1951 of a jointly-owned company, the Titanium Metals Corporation of America at Henderson, Nevada. Magnesium metal is used in the reduction of titanium and the magnesium values are then recovered as $MgCl_2$, which is electrolyzed to recover both magnesium and chlorine. In the 1960's, NL Industries began an active investigation into the possibilities of producing and selling commercial quantities of magnesium metal. In searching for additional sources of magnesium, NL Industries became aware of the potential of the Great Salt Lake. A review of the various sources of magnesium led to the selection of the Great Salt Lake as the preferred place to locate a plant.

During 1965 and 1966, NL Industries conducted pilot operations to select the best process for use with Great Salt Lake brines. Solar ponds were constructed at Burmester, Utah and a pilot plant for producing cell feed was built at Lakepoint, Utah. Product from this pilot plant fed a prototype cell at TIMET in Henderson, Nevada. From this program a decision was made in 1969 to build a magnesium plant at Rowley, Utah, to utilize brine from the Great Salt Lake.

The plant was completed in 1972, but design problems with less than expected productivity required closure in 1976 to redesign critical processes. The plant re-started production in 1977 and operated at below its 36,000 tons/year capacity until 1980 when the facility was sold to AMAX Inc. The rising Great Salt Lake breached parts of the 15 mile dike enclosing the Stansbury Basin Solar Evaporation Ponds in 1983. The dike was rebuilt at tremendous costs to maintain the ponds against still rising level of the lake. The dike was breached once again in 1986 when the lake hit the 100 year high level record. Rather than closing the magnesium facility AMAX Inc. withdrew from Stansbury Basin and constructed new solar evaporation ponds near Knolls, Utah next to the West Desert Pond created by the State of Utah West Desert Pumping Project which was built to control flooding in the lake. AMAX's Knolls Solar

Evaporation Pond system was completed in 1988 and brine was pumped from the States West Desert Lake until July 1989. In August 1989 AMAX Inc. sold the magnesium facility to the RENCO Group Inc. (a privately held company) and was renamed Magnesium Corporation of America (Magcorp).

Magcorp contributes approximately $4.5 million in tax dollars to the States economy and over $20 million directly to Utah's economy.

ROWLEY MAGNESIUM PROCESS

Solar Evaporation

The first step in the process is the use of solar energy to perform the major part of the concentration of the magnesium values. A 50,000 acre pond system was built in the Stansbury Basin which is west of Stansbury Island and south of Badger Island in 1970. This basin is divided into three ponds where the desired brine concentration of 7.5% magnesium by weight is achieved. The Knolls Solar Evaporation Ponds System constructed within 25,000 acres in 1988 enabled Magcorp to capture a 10 year supply of brine after one and one half years of harvesting. The progressive concentration of magnesium is illustrated in Table 1, which shows the relative concentrations of the Great Salt Lake and the effluent from the three ponds in sequence. The magnitude of this evaporation step is illustrated by the fact that the less than three percent of the volume of the original Great Salt Lake brine reaches the plant holding pond. In concentrating the brine over 3,000,000 tons of salts are deposited in the ponds each year.

Table 1. Percent of each constituent

	Great Salt Lake Brine	Effluent Pond No. 1	Effluent Pond No. 2	Effluent Pond No. 3 to Holding Pond
Mg	0.4	2.0	4.5	7.5
K	0.3	1.5	3.6	0.8
Na	4.0	7.0	2.6	0.5
Li	0.002	0.01	0.024	0.06
B	0.0018	0.009	0.021	0.054
Cl	7.0	14.0	16.0	20.3
SO_4	1.0	5.0	5.3	4.4

Because of the seasonal variations in weather and temperature in Utah, evaporation of this quantity of brine must take place within the three or four hottest and driest months starting sometime in May. When the proper concentration is achieved, the concentrated brine is pumped to a holding pond, which can store up to two years' supply of brine. This storage is required to ensure an adequate supply of brine during a year when the weather conditions would not permit adequate evaporation. Additional separation of solids and concentration is usually achieved in the holding ponds. Thus, the concentration of magnesium is usually brought to an excess if 7.5% $MgCl_2$.

Feed Preparation

The feed preparation for the electrolytic cells consists of further concentrating the brine, removing unwanted impurities, adjusting for the correct proportions of other salts with the $MgCl_2$ and the melting and final purification of the molten $MgCl_2$. The process steps are outlined in Figure 1. The brine is pumped in from the holding pond and is first heated and concentrated. After concentrating, it is sent back to one of the holding ponds and allowed to cool to facilitate removal of potassium by crystallization of kainite and some carnallite double salts. The supernatent is then reacted with $CaCl_2$ and the resulting gypsum is precipitated and collected in a thickener. This reaction is as follows:

Equation 1

$$MgSO_4 + CaCl2 + 2H2O \qquad CASO4 + 2H2O + MgCl2$$

This step removes most of the sulfate, which is not acceptable in electrolytic cell feed. The brine next passes through a liquid-liquid extraction step whereby the boron values are removed, as this impurity is also very detrimental to electrolytic cell operation. Next, the brine passes through a preheater in which it is heated and further concentrated prior to being fed to spray dryers. The spray dryers convert the concentrated brine to a dry $MgCl_2$ powder. This product contains about 4% MgO and 4% combined water. The MgO is formed by hydrolysis of $MgCl_2$ as shown:

Equation 2.

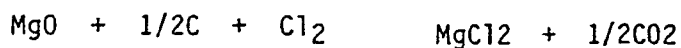$$MgCl_2 + H20 \quad\quad MgO + 2HCl$$

Utilization of energy in the feed preparation step of the plant is extremely efficient. In order to ensure the availability of some on-site power, part of our power is generated in gas turbines. After producing power the exhaust gases pass from the generator to the spray dryer at approximately 930°F where the heat is used to form the magnesium chloride powder. These gases leave the spray dryer at about 550°F and are then used as the heat source in the concentrating and preheating of the brine pripr to feeding it to the spray dryer. This gives an overall energy utilization of over 80%. Gas burners are available to operate the spray dryer when the turbines are not in use.
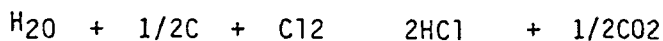
The spray-dryed powder is stored until fed to a melt cell. In this vessel the powder is melted and further purified with chlorine and other reactants to remove MgO, water, bromine, and other impurities including most heavy metals. This is a continuous process and as powder is fed to the melt cell, molten salt overflows from the melt cell through a launder and into a reactor cell where the purification is completed., The reactor cell vessles are brick lined and approximately 13' X 17' X 8' deep. The melt temperature is kept at 1550°F by providing sufficient alternating current to maintain this temperature.

Removal of impurities is complex, but can be summarized by the following simplified equations:

Equation 3.

$$MgO + 1/2C + Cl_2 \quad\quad MgC12 + 1/2CO2$$

Equation 4.

$$H_{20} + 1/2C + C12 \quad\quad 2HCl + 1/2CO2$$

Equation 5.

$$MgBr_2 + C12 \quad\quad MgCL2 + Br2$$

The product continuously overflows from the reactor cells and is fed directly to the electrolytic cells. The specifications for this material are as follows:

Bromine	Less than 0.01%
Boron	Less than 0.001%
Magnesium Oxide	Less than 0.10%
Water	Less than 0.10%
Sulfate	Less than 0.01%

HCl produced from the chlorination of water as shown in Equation 4 is recovered as concentrated hydrochloric acid which is subsequently reacted with limestone (oolitic sand) to produce the $CaCl_2$ needed for desulfation:

Equation 6.

$$2HCl + CaCO_3 \quad CaCl2 = H2O + CO2$$
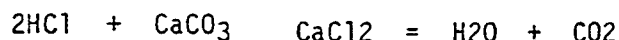
Excess unreacted chlorine in the offgas is thermally converted to HCl in a burner at 1850°F. This HCl is also neutralized.

Production and Handling of Magnesium Metal

Molten salt containing about 94% $MgCl_2$ is transferred to the electrolytic cells on a rigid schedule. The cells at Rowley are essentially a modification of the I.G. Farben cell developed in Germany in the 1930's. These are normally referred to as I.G. cells and figure 2 shows a sketch of a typical cell. This cell consists usually of three to five graphite anodes with steel cathodes on either side. Semiwalls extending from the top of the cell down into the bath isolates two gas compartments. The gas compartments around the anode collect the chlorine gas, which is generated on the anode surface. The chlorine is then evacuated to the chlorine recovery plant. The cathode compartment collects the magnesium metal which floats on the salt. The magnesium metal is removed from the cells each day and sent to the cast house. (Sufficient air is passed over the cathode compartment to remove any fumes and then through a scrubber in order to keep the environment around the cells in safe working condition.) Sealed

cells were developed in the mid 1980's to further improve capture of cell fumes and improve magnesium recovery rates while improving electricity usage. The metal transferred to the casthouse is conditioned, purified as needed, alloyed as required and poured into molds for shipment. These molds may vary from 16 pounds to 500 pounds or more and may be in the form of special shapes in order to serve specified end uses. Several alloys as well as high purity magnesium form part of products available.

USE OF PRODUCTS

In 1991 the total free world consumption of magnesium approached 243,500 short tons of which about 120,000 tons were consumed in the United States. The plant at Rowley is the third largest in the free world and represents about 15% of the world production and 30% of the domestic production.

The largest single use of magnesium is for alloying aluminum to provide strength, malleability, and corrosion resistance. The aluminum beverage can is the largest single user, but significant quantities of aircraft and automotive sheet also require magnesium additions.

When magnesium is added to iron, brittle gray iron is transformed into higher strength ductile iron. Automotive crankcases, which used to be forgings, are now ductile iron. Magnesium powder is injected into steel to remove embrittling sulphur compounds.

Magnesium is used as a reducing agent in the production of titanium, zirconium, hafnium, and beryllium. Other chemical uses are as a grignard reagent, motor oil additive, pyrotechnic material, and as consumable anodes for cathodic protection.

As a structural material, magnesium alloy AZ91 is most viable as a die casting for chain saws, lawn mower housings, the famous Volkswagen Beetle engine, clutch housings, transmission casings and various automotive parts. Extrusions, tool plate, sheet and plate also find a variety of uses.

While most of the magnesium produced is for domestic consumption, Magcorp has shipped material overseas primarily to Europe, South America, and Japan.

A co-product to magnesium is chlorine, most of which is recycled in the process; however, excess chlorine (approximately 10,000 ton/year) is being sold in the Salt Lake area and the western United States. Chlorine has a variety of chemical uses and is also used in water purification. The plant at Rowley provides a Utah source of chlorine to replace that previously shipped in from the Pacific Northwest. Chlorine in excess of use and sales is also converted to HCl or $CaCl_2$.

Other byproducts presently being considered from the production of magnesium at Rowley, Utah are $CaCl_2$, HCl, lithium compounds, and bromine compounds. In addition, millions of tons of salt are being deposited in the ponds. These salts are largely sodium chloride and various sulfates. Sales of these salts, direct or after modification, provides added income. Other byproducts from the pond system and the plant are potential income producers.
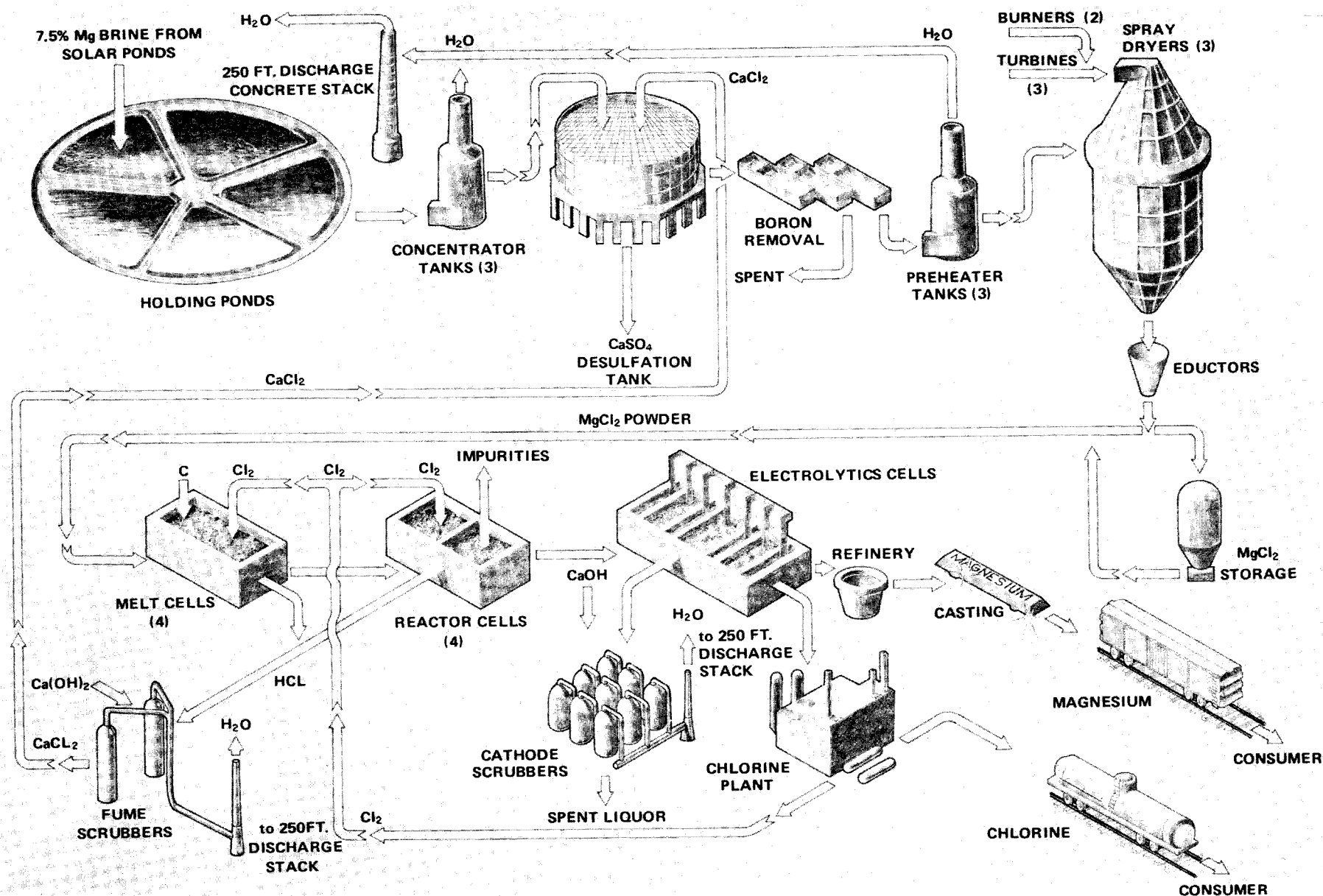
Figure 1. Schematic diagram showing the production of magnesium metal and chlorine gas from the brines of the Great Salt Lake, Utah.